INTRA- AND INTER-ANNUAL BREEDING SEASON DIET OF LEACH'S STORM-PETREL (*OCEANODROMA LEUCORHOA*) AT A COLONY IN SOUTHERN OREGON

by

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A THESIS

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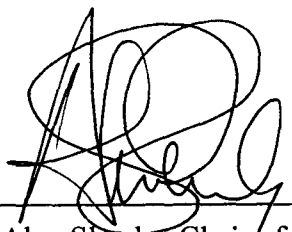

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Title: INTRA- AND INTER-ANNUAL BREEDING SEASON DIET OF LEACH'S STORM-PETREL (*OCEANODROMA LEUCORHOA*) AT A COLONY IN SOUTHERN OREGON

The oceanic habitat varies on multiple spatial and temporal scales. Aspects of the ecology of organisms that utilize this habitat can, in certain cases, be used as indicators of ocean conditions. In this study, diet of the Leach's storm-petrel (*Oceanodroma leucorhoa*) is examined to determine if evidence of changing ocean conditions can be found in the diet. Regurgitations were collected from the birds in order to describe diet. Euphausiids and fish composed 80 – 90% of the diet in both years, with composition of each diametrically different between years. Other items found in samples included hyperiid and gammariid amphipods, cephalopods, plastic pieces and a new species of Cirolanid isopod. Selected oceanographic indices did not explain the differences seen in diet by date. Also, the effects of self-oiling of the birds by their own regurgitation on survival as estimated by recapture rates was investigated. No significant effects were found.

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This thesis is dedicated

to my parents for supporting me in all my endeavors,

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CHAPTER I

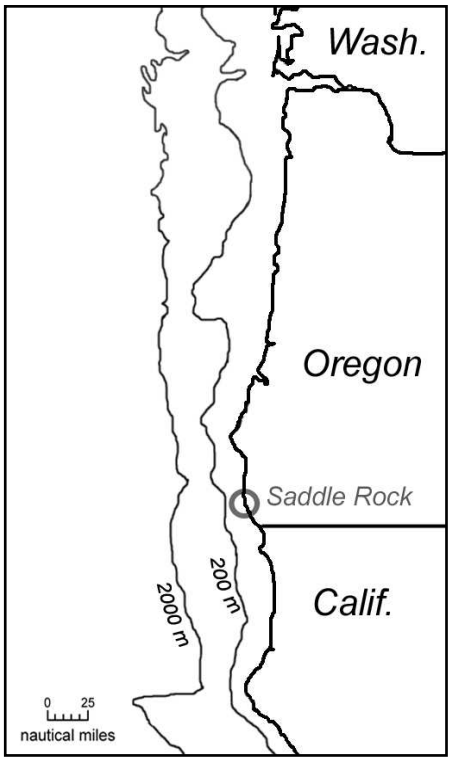
INTRODUCTION

THE LEACH'S STORM-PETREL AT SADDLE ROCK, OREGON

The Leach's storm-petrel (*Oceanodroma leucorhoa*) is a small, highly pelagic (40g) seabird in the order Procellariformes. Leach's storm-petrels are found breeding in temperate to sub-polar regions in both the Atlantic and Pacific Oceans. Colonies of this seabird are found on the West Coast of the United States from the Aleutians to Baja California (Huntington et al. 1996). In Oregon, Leach's storm-petrels are most common in the southern quarter of the state, likely due to limited suitable habitat in the northern portion of the state. Saddle Rock, the site of this study, has been estimated to be home to 50,000 breeding pairs of Leach's storm-petrels, making it the 4th largest colony in Oregon (Varoujean & Pitman 1979).

Saddle Rock, a 1/3 km^2 seastack, is located at 42.250° N, 124.415° W, and is part of the Oregon Islands National Wildlife Refuge, administered by the U.S. Fish and Wildlife Service (Figure 1). Island topography consists of a south and north

Figure 1: Map of study area.



stack connected by a lower elevation saddle area. The upper surface of the island is covered with a layer of sandy topsoil dominated by *Juncus* sp. and common cowparsnip (*Heracleum maximum*), and includes powdery liveforever (*Dudleya farinosa*), red fescue (*Festuca rubra*), lupine (*Lupinus* sp.) and miner's lettuce (*Claytonia perfoliata*). Introduced vegetation includes tansy ragwort (*Senecio jacobaea*) and South African native ice plant (*Carpobrotis chilensis*). The only structure on Saddle Rock is an elevated plastic-plank boardwalk built by the Fish & Wildlife Service in 2004 to protect burrows while providing access to netting platforms.

Leach's storm-petrels are the primary inhabitants of Saddle Rock, sharing the island with a few nesting western gulls (*Larus occidentalis*) and one nesting peregrine falcon (*Falco peregrinus*). Both of these species and visiting great horned owls (*Bubo virginianus*) will prey on the storm-petrels when the opportunity presents itself, but the main predation pressure on the birds is exerted by river otters (*Lutra canadensis*). River otters were first observed at the colony in 2001 (R. Pitman, pers comm.), and seem to have displaced *L. occidentalis* as the primary predator.

SELF-OILING EFFECTS ON LEACH'S STORM-PETREL

Avian research has been occurring at Saddle Rock with varying effort since 1979. Research initially began as an annual banding effort to create a known-age population of banded birds. It was during these initial banding excursions that R. Pitman observed the incidence of self-oiling in netted Leach's storm-petrels. All Leach's storm-petrels produce a rich, diet-based stomach oil. This oil is thought to be an advantage for the birds because the oil provides a high source of energy in a lesser volume than solid food items (Place et al.1989). Breeding storm-petrels provision their young chicks with this

oil, which becomes mixed with more solid food items as the chicks grow (Watanuki 1985). Stomach contents, including the oil, are often ejected by the breeding adult upon capture in a mist-net, most likely as a predation defense. Ejection of stomach contents while in the net often causes the birds to become covered in their own regurgitant ('self-oiling'). Oil-coated plumage may be a less effective insulator, and may negatively affect survival.

CONTRIBUTION BY CO-AUTHOR

In Chapter II of this thesis Robert Pitman and I investigate the effects of self-oiling on survival. R. Pitman initiated the assessment of self-oiling using oiling codes in 1988 and facilitated collection of self-oiling data in subsequent seasons, with the exception of 2004 and 2005. Netting crews, including myself, collected data in these years. I undertook the analysis and interpretation of data, with input from Mr. Pitman, Dr. Jan Hodder and Dr. Alan Shanks.

CHAPTER II

SELF-OILING EFFECTS ON RECAPTURE RATES OF LEACH'S STORM- PETRELS

INTRODUCTION

Most Procellariform seabirds, with the exception of diving petrels (Pelecanoididae), concentrate dietary lipids in the proventriculus, forming an energyrich stomach oil (Jacob 1982). The stomach oil is fed to chicks and is an energy source for adults (Place, et al. 1989), but can also be ejected at the approach of an intruder. This response to intruders is hypothesized to have two functions: (1) to lighten the birds' load before flight, and (2) to deter predation (Warham 1977). Effects of this oil on avian predators have been seen to include loss of flight capability and death from the reduced insulation of oiled feathers. Warham (1977) hypothesized that the plumage of the petrels, who appear able to remove the oil by preening, may have special properties that protects them from the effects of self-oiling.

Ejection of stomach oil and solid food items is often observed in Leach's storm-petrels (*Oceanodroma leucorhoa*) upon capture in mist-nets. During the course of mist-netting at the Saddle Rock colony in southern Oregon, we observed birds returning with large food loads become covered with oily regurgitant almost immediately upon capture in the net. The birds observed regurgitating were most likely breeding birds returning to the

colony to provision chicks. Birds left in the net for more than a very short period of time tended to become more covered in the oil. We hypothesized that birds oiled by their own regurgitant during the course of our studies would exhibit reduced survival, as estimated by recapture rates.

METHODS

This study took place at the Saddle Rock colony, a seastack in southern Oregon approximately 30 km north of the California border. Mist-netting and banding have occurred opportunistically on the island for over 25 years, for the purpose of identifying and tracking a population of known-age birds. Self-oiling was quantified for several years from 1988 to 2005. In 2004 an intensive netting and banding program was conducted as part of a mark-recapture population estimate. This study makes use of the 2004 data for within-season self-oiling analysis.

Mist-netting of the storm-petrels took place at night (typically 2130 – 0400), using a 30-gauge 12-meter nylon or cotton net. Effort for this study was not standard over the years, as netting was part of the larger banding study. We recorded the amount of self-oiling of captured birds on one night of netting in 1988, 1990 and 1991, three nights in the years 1992 to 1997, 20 nights in 2004, and for eight nights in 2005. Self-oiling was quantified as four categories based on percentage of total body oiled: no self-oiling (<5%), light (5 – 10%), medium (10 – 15%) and heavy (15%+) self-oiling. We assessed effects of self-oiling on survival of the birds by comparing rates of recapture in each of the self-oiling categories. We considered recapture of the bird after it had been oiled as indicating survival if the recapture event occurred on a subsequent night or in a subsequent year. Recapture events on the same night as initial capture were not used in

this study. Survival was not assumed for non-recapture events. All years were used to investigate inter-annual recapture rates, and data from 2004 was used for assessment of within-season recapture rates.

We used an intrinsic hypothesis G-test (Sokal & Rohlf 1995) to test the hypothesis that there were no differences between the overall recapture rate of birds at the colony (5%) and recapture events of self-oiling categories seasonally and inter-annually. In each test, the initial G statistic was adjusted using Williams correction (Sokal & Rohlf 1995). For all tests, df = 2.

RESULTS

A comparison of the recapture self-oiling category shows that higher rates of recapture occurred inter-annually in the light and heavy oiling categories. Non-recapture events were higher inter-annually in the light self-oil category and equal in the heavy-oil category.

Comparing within-season recapture rates shows that recapture rates were higher in the none, medium and heavy self-oil categories. Inter-annual recapture rates were only slightly higher in the heavy-oiling category. No significant differences were observed for any of the recapture categories (Table 1). We found no significant difference between the percentage of recapture oiling events both within season ($G_{adj} = 0.381$, $p = 0.87$) or between seasons ($G_{adj} = 0.478$, $p = 0.85$), based on self-oiling category. Heavy self-oiling has the greatest potential to adversely affect the storm-petrels. Within this category we found a large, but not statistically significant, difference of 5% between the percentage of birds recaptured seasonally versus inter-annually, with capture at a higher rate inter-annually than seasonally. A 4% difference was found between

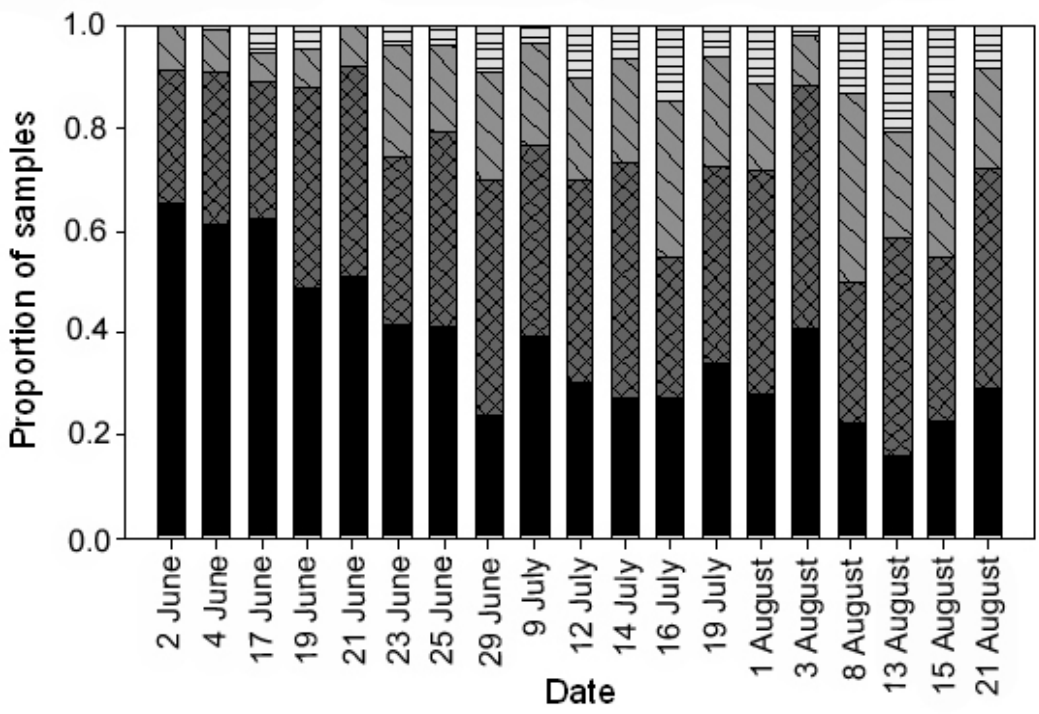
recapture and non-recapture heavy self-oiling events within seasons, with recapture occurring less often than non- recapture events. We found little difference in the percentage of inter-annual recapture v. non-recapture heavy self-oiling events, or in percentage of non-recapture inter-annual and seasonal heavy self-oiling events.

Table 1. Capture fate of differentially oiled birds (number and percentage within recapture category)

	RECAPTURED				NOT RECAPTURED			
	Interannual		Seasonal		Interannual		Seasonal	
OILING CATEGORY	**Number**	**%**	**Number**	**%**	**Number**	**%**	**Number**	**%**
No Oiling (0 – 5%)	112	0.51	105	0.40	2165	0.48	1037	0.39
Light Oiling (5 – 10%)	53	0.24	102	0.39	1303	0.29	978	0.37
Medium Oiling (10 – 15%)	37	0.17	46	0.18	739	0.16	478	0.18
Heavy Oiling (15% +)	18	0.08	9	0.03	325	0.07	186	0.07

Incidence of oiling event categories within the 2004 season (Figure 2) was tracked by date and shows the following pattern: no and light oiling events are predominant in the early part of the season, with a few moderately oiled birds. Incidence of light, moderate and heavy oiling events increased through the season to peak around mid-August. Incidence of birds displaying no oiling declines accordingly. From mid- to late August, incidence of heavy and moderate oiling events decline, with heavy oiling incidents disappearing completely by the end of the netting season.

Figure 2: Proportions of captures in the no (solid), light (cross-hatch), medium (diagonal hatch), and heavy (horizontal hatch) self-oiling categories by date in 2004.



DISCUSSION

The pattern of mid- to late season increase in the incidence of heavily-oiled birds (with which we are most concerned) may be explained by changes that occur in Leach's storm-petrel diet through the breeding season. As chicks become larger, breeding adults are bringing larger food-loads back to the colony (Vermeer & DeVito 1988), likely resulting in heavier self-oiling. Percentage of oiling category represented by the 'medium' and 'heavy' categories does increase over the season. Our data indicate that light to moderate self-oiling does not affect the survival of Leach's storm-petrels, but may deter their return to the colony within a season. However, as the season progresses, fewer dates remain on which to capture the birds, therefore decreased seasonal recapture of heavily oiled birds may not indicate decreased survival, but may instead reflect

heavier food loads at the end of the season and lower recapture effort. We conclude that the patterns seen in self-oiling at this colony are not indicative of decreased survival with self-oiling, in keeping with other studies of self-oiling incidents of Procellariform seabirds.

BRIDGE: LEACH'S STORM-PETRELS AS MONITORS OF THE MARINE ENVIRONMENT

Leach's storm-petrels are surface-seizers, relying on prey items found in the neuston layer, from which they forage by plucking their prey from the surface while hovering over or sitting on the water. The birds, too small to be fitted with tagging or monitoring devices, are assumed from previous studies of diet to forage at night, or at dusk or dawn, when diel vertically-migrating prey species are found in the neuston. Little is known about this species' winter diet (Huntington et al.1996).

Surface-feeding seabirds, such as the Leach's storm-petrel, rely on prey that is more varied in distribution than do species of diving seabirds (Montevecchi 1993). Certain species of surface feeders have been demonstrated to be excellent monitors of the marine environment, at times providing striking evidence of large-scale changes in oceanographic conditions via population declines due to unobtainable prey (Montevecchi 1993).

In Chapter III, I describe the diet of Leach's storm-petrel at the Saddle Rock colony in 2004 and 2005. The stomach oil and diet items regurgitated by Leach's storm-petrels were collected in 2004 and 2005 in order to investigate storm-petrel diet. As part of data protocol for the population estimate, each captured bird was banded, and wing chord measurements, brood patch scores and molt scores were taken. Due to rigorous

requirements for netting conditions, nets were not always kept open all night.

In order to answer the question of whether influences of ocean conditions can be seen in the diet composition of Leach's storm-petrel, I investigate and describe variation seen in the diet between months and between years. I undertake a multivariate analysis and comparison of the diet with variables indicating ocean conditions. Variation of diet composition by date is also described. Given the spatial range of Leach's storm-petrel foraging grounds and the resolution of ocean variables considered, only mesoscale ocean features (100 – 1000 km: Hunt & Schneider 1987) are considered in this study.

CHAPTER III

INTRA- AND INTER-ANNUAL VARIATION IN LEACH'S STORM-PETREL DIET

INTRODUCTION

Seabird diet studies

Investigation of the diet and foraging behavior of seabirds that rely on production in marine environments offers a unique alternative to direct sampling. In addition to providing information about the birds themselves, study of seabird diet can yield information about the type of habitat at a given location (e.g. Springer et al. 1996), changes in prey base organisms (e.g. Montevecchi & Myers 1995), seasonal and long-term oceanographic change (e.g. Abraham & Sydeman 2004 & 2006) and the presence of pollutants in the marine environment (e.g. Goede & deBruin 1984; Ryan 1987).

This study describes patterns of intra- and inter-annual variation in the breeding season diet of the Leach's storm-petrel (*Oceanodroma leucorhoa*), at the Saddle Rock colony in southern Oregon. Leach's storm-petrels are oceanic, coming to land only to breed, and then arriving only at night to avoid predation. The breeding season of these seabirds typically lasts from April to November (Harris 1974; Ainley 1975).

The diet of Leach's storm-petrels reflects the oceanic environment in which they spend most of their time, and consists of organisms foraged from the neuston (Linton 1979;

Hedd 2006). The foraging range of Leach's storm-petrels can extend up to 220 km from the breeding colony (Steele & Montevecchi 1994: as estimated for a colony in Nova Scotia), but cannot be directly assessed due to the small size of the animals, which precludes the use of tracking tags. Oceanic distribution of Leach's storm-petrels tends to be beyond the continental shelf break in areas of warm water (Wiens & Scott 1975; Brueggeman 1992), negatively correlated with frontal gradients and negatively associated with other bird species and the surface chlorophyll maximum (Briggs, et al. 1987; Hoefer 2000; Ainley et al. 2005). Studies of at-sea distribution are conducted during daylight hours, but breeding season diet indicates nocturnal foraging, thus daytime distribution may not indicate areas of intense foraging (Hoefer 2000).

A small number of studies have quantified the breeding season diet of Leach's storm-petrel in the Pacific in various oceanographic regions (Watanuki 1985; Vermeer & DeVito 1988), but little work has been done in the California Current region. Diet composition of Leach's storm-petrel at the Saddle Rock colony in southern Oregon in 2004 and 2005 was investigated for three purposes: (1) to describe the diet, (2) to introduce the element of inter-annual variation, and (3) to investigate the possibility that the influence of ocean conditions and water mass movement can be seen in the prey composition of this species.

Oceanography of the California Current off southern Oregon

The California Current, an eastern Pacific boundary current characterized by wind-forced equatorward flow in the summer months, is the primary feature of coastal and offshore waters of Oregon. Variation in strength and direction of wind forcing in this region also drives the summer phenomena of alternating offshore Ekman transport

(generating upwelling of cold, nutrient-rich water that fuels productivity) and relaxation periods of onshore flow (downwelling) (Laurs 1967). In summer months, the ocean conditions seaward of the Saddle Rock colony are influenced by the presence of Cape Blanco approximately 50 km to the north (Barth & Smith 1998). During a typical summer, the southward-flowing jet of the California Current is relatively linear until reaching Cape Blanco, where the jet is deflected offshore, marking the beginning of the formation of mesoscale eddies and offshore-flowing filaments further to the south (Mooers & Robinson 1983; Barth et al., 2005; Huyer et al., 2005).

This physical pattern is borne out by the apparent pattern of the biota. Euphausiids are considered an indicator species of particular water masses (e.g. inshore v. offshore, southern v. northern) (Brinton 1981; Brinton & Reid 1986; Peterson et al. 2000; Gómez-Gutiérrez et al. 2005). For example, *Euphausia pacifica* and *Thysanoessa spinifera* are respectively defined as shelf-break and shelf species to the north of Cape Blanco, but this pattern is gradually altered south of the Cape, with *T. spinifera* and *E. pacifica* found both on and off the shelf due to entrainment in mesoscale features such as eddies and jets (Peterson et al. 2000; Ressler et al. 2005). Formation of these mesoscale features is a gradual process, but once formed, features can persist for days to months. Of special interest for this study is an upwelling jet that forms south of Cape Blanco, which can send nutrient- and phytoplankton-rich upwelled water over 100 km offshore, and serves as an advection mechanism for zooplankton (Barth & Smith 1998; Ressler et al. 2005).

MATERIALS AND METHODS

Study site

Saddle Rock lies roughly 50 m offshore. The island was accessed by foot at tides lower than -1.0 (depending on sand depth in the channel), and by swimming at all others. The main topographic features of Saddle Rock are two conical stacks approximately 100 m high, connected by an area of lower elevation, the 'saddle' area. Birds were captured at this location using a single 12 m 38 gauge mist net set up at two neighboring locations on alternating nights, one across the saddle and one at the base of the island's north stack.

Sample collection and content identification

Netting occurred at night during the period when the storm-petrels were active at the colony (typically 2130 – 0400). Nets were run when wind speeds were < 10 km per hour in dry weather conditions. During the breeding season, Leach's storm-petrels have a tendency to regurgitate food items, which may be used as a predation defense (Warham 1977). These regurgitations were collected directly from the birds by holding a Whirl-Pak lightly over the captured bird's head. Once free of the net, birds were briefly inverted to induce further regurgitation. If a sample was not caught, it was picked up from the ground. The samples were then labeled and put on ice for transport off the island. At the end of each night's collections, samples were separated into two categories: those containing oil, and those containing solid items (in which oil might be present). Samples containing solid items were preserved in 5% formaldehyde and later transferred to 70% ethanol for long-term storage. Seventeen sampling dates from 2004

(17 June – 21 August, n = 433 samples with identifiable items) were used in this analysis (Table 2). Three dates with fewer than five samples per night were omitted from this study, leaving five sampling dates in 2005 (20 June – 21 August, n = 176).

Diet items were examined using compound and dissecting scopes and identified to lowest possible taxonomic level. Due to the digested nature of the samples, items were counted but not weighed. A conventional diet ennumeration such as this is very useful in identifying the items on which a species is feeding, but can favor some items over others (e.g. items with hard parts) due to differential digestion rates (Hyslop 1980; Rosenberg & Cooper 1990). Ennumeration of samples in this manner also fails to take into account the size of the item, and thus may over-emphasize the importance of smaller items in the diet. Otoliths were identified using an established reference collection and were verified by an expert, as were nematodes. Literature (e.g. Stebbing 1906; Kathman et al. 1984; Vinogradov 1996) and the assistance of experts were used to identify other diet items.

Diet composition and indices of species diversity

The complete data set of all items was used to describe species composition and to calculate frequency of occurrence of items in the diet, as well as indices of diversity and evenness. The Shannon-Weiner (H') index of diversity was used to examine species diversity between months in 2004 and between years. Pielou's Evenness Index (J') was used to assess evenness of months and years. Within-season diet analysis of 2005 was not assessed by month due to the comparatively low number of dates per month in that year (Figure 3).

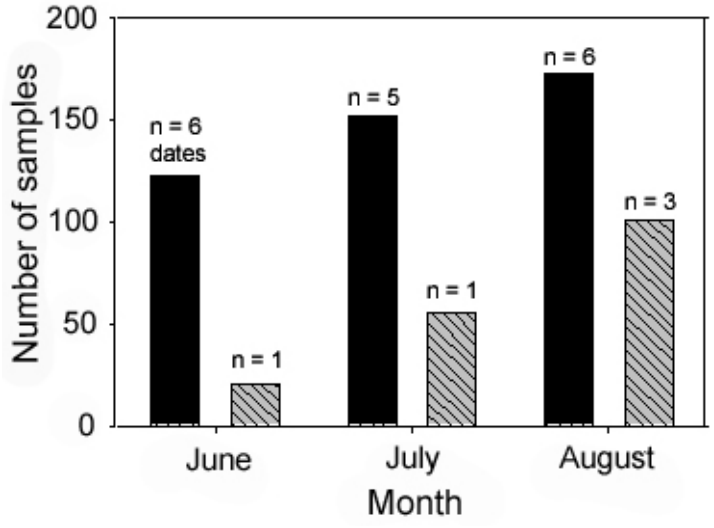


Figure 3: Number of samples and number of dates sampled by month in 2004 (solid bars) and 2005 (hatched bars).

Multivariate community analysis of within-season diet

A series of non-parametric methods of species composition analyses, based on Bray-Curtis similarities, were used for the purpose of investigating variation in the diet assemblage as a whole. Non-parametric methods were used due to unequal sample sizes, unequal variance, and a large number of zeros present in the data (Clarke & Warwick 1994). Methods such as these have previously been used to describe diet composition (Lønne & Gabrielsen 1992; Braccini 2005). The following analyses used the PRIMER 6 software package (Plymouth Marine Lab 2006).

Because not all diet items could be identified to species level, diet items were combined together into eleven higher taxonomic categories (class or order) for analyses. In this way community composition could be analyzed in a manner consistent with general taxonomic resolution of the identification method. The combination of species that have different ecological functions into larger groups may, however, sacrifice power in determining possible causes of diet variation.

Initial interest lay in determining if species composition by date was significantly different between months, since Leach's Storm-petrel diet has been shown to have a seasonal component (Watanuki 1985; Vermeer & DeVito 1986). Before assessing significance of month by date, a global ANOSIM (analysis of similarity) procedure was applied. The ANOSIM, which is used to determine statistical significance of differences between pre-determined (*a priori*) groupings in the diet data, was to test differences between samples grouped by date, because, as Clarke & Warwick (1994) state, 'a pre-requisite to interpreting community differences ... should be a demonstration that there are statistically significant differences to interpret'. This test was performed on an assemblage-by-sample (11 taxa x 433 samples) resemblance matrix of relative abundance of the 2004 data, square-root transformed. A maximum number of 1000 permutations was used in these tests. If the data permitted a larger number of permutations, then 1000 permutations were sub-sampled from the complete distribution. Following a significant result, the grouping of months by date were tested with a global ANOSIM on a square-root transformed assemblage-by-date relative abundance matrix. All following procedures use the same assemblage-by-date square-root transformed resemblance matrix of relative abundance (11 taxa x 17 dates), except where noted below.

Hierarchical cluster analysis and non-metric multi-dimensional scaling

In addition to answering *a priori* questions, natural groupings in the diet were discerned using cluster analysis, in conjunction with non-metric multidimensional scaling (NMDS). The previously specified matrix, but with rare taxa removed, was used for both the cluster analysis and NMDS of date associations. Taxa were considered rare

in the diet if they did not compose more than 0.5% of the diet. The taxonomic levels of analysis used are indicated by bold text in the first column of Table 3, with rare taxa indicated by plain text. Cluster analysis and NMDS of species associations used this same matrix, but without application of a transformation (Clarke & Warwick 1994).

Hierarchical cluster analysis based on group-averaged rank Bray-Curtis similarity was performed on both assemblage and date data. Dendrograms resulting from cluster analysis were delimited at the 78% similarity level for the date association dendrogram, and where 60% similarity level for the species association dendrogram.

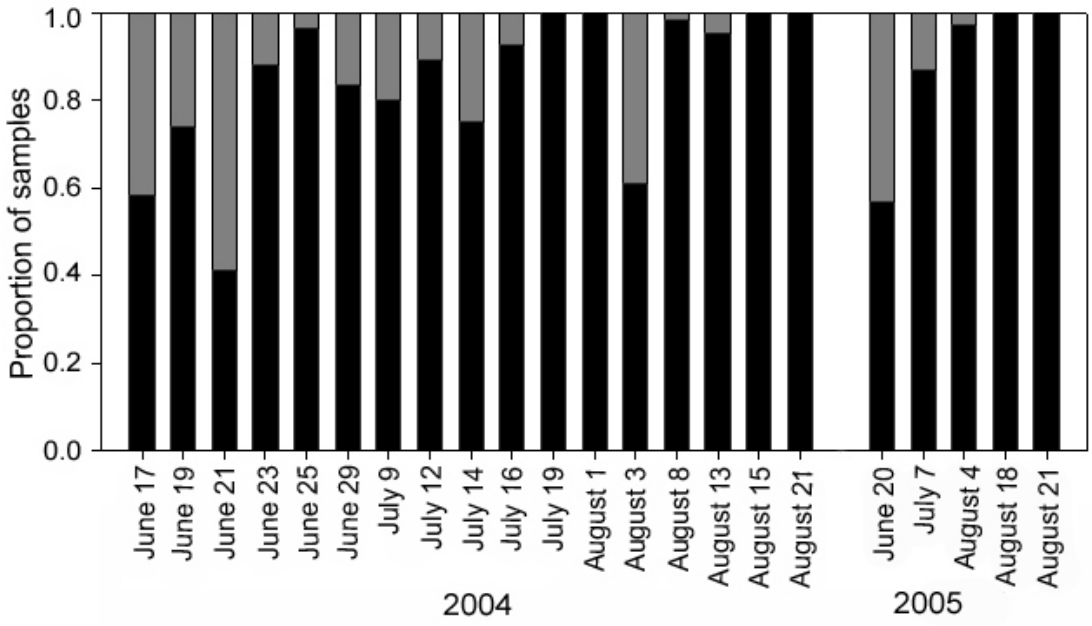
NMDS was used to investigate the relationship between date and assemblage data in 2- and 3-dimensional space defined by Bray-Curtis similarities. Twenty-five restarts were used to alleviate the possibility of reaching a local minimum configuration. Clusters were overlaid on the 3-dimensional NMDS to further illustrate relatedness of sampling dates and biotic data. Cluster analysis and NMDS was followed by a SIMPER analysis to determine the percentage of which each taxa contributed to similarity of cluster groups and the equitability of contribution by date to taxa clusters.

RESULTS

Oil v. Solid

Percentage of samples containing oil in each year declined as the breeding season progressed (Figure 4), as would be expected due to the apparent changing diet and energetic needs of the chicks (Watanuki 1985; Vermeer & DeVito 1988). Samples containing only oil continued to occur in July, perhaps due to second nesting attempts. The reappearance of samples of only oil in August may be due to non-breeders regurgitating small amounts of oil.

Figure 4: Proportion of samples composed of solid (dark) versus oil (light) in 2004 and 2005.



Prey occurrence: general

A total of 2141 diet items were identified in this study. The major prey items of Leach's storm-petrels at Saddle Rock are members of an ecologically similar community of mesopelagic diel vertical migrators and neustonic organisms that are preyed on by Leach's storm-petrels across the Pacific basin (Watanuki 1985; Vermeer & DeVito 1988). The two major food items, fish and euphausiids, together represented >80% of total diet in both years. The percentage of each item in the diet was diametrically different by year, with euphausiids composing 28% of the diet by number and fish 54% in 2004, while in 2005 fish composed 28% and euphausiids 56% of the diet (Table 2). Frequency of occurrence of fish in the diet was similar between years, but the frequency of occurrence of euphausiids was 19% higher in 2005 than in 2004.

Twenty-two otoliths of the 1007 prey items identified as fish were in sufficient condition to allow identification. Fishes identified from otoliths were primarily myctophids (82%), with pencilsmelt (*Microstoma* sp.: 14%) and eelpout (unidentified Zoarcid: 5%) comprising the remaining percentage. Fishes classed as unidentified myctophids were identified by the presence of characteristic photophores in the samples. Of the species of myctophid that were present in the diet (as identified by otoliths), two commonly occur in waters off Oregon. These are the northern lampfish (*Stenobrachius leucopsarus*), and the California headlightfish (*Diaphus theta*) (Pearcy 1964). California flashlightfish (*Protomyctophum crockeri*), dogtooth lampfish (*Ceratoscopelus townsendi*) and bigfin lanternfish (*Symbolophorus californiensis*) are more rarely encountered in the waters off Oregon (Doyle 1992: based on larval estimates; Pearcy 1964). One of the non-myctophids, *Microstoma* sp., has not been recorded off the coast of Oregon (Cohen 1958), and is generally associated with tropical and subtropical mesopelagic waters.

Seventy-nine percent of euphausiids in the diet were identifiable to species. *Euphausia pacifica* was the most common (93%), with smaller percentages of *Nematoscelis difficilis* (5%) and *Thysanoessa spinifera* (2%) present in the diet. *E. pacifica* and *T. spinifera* are common species off the Oregon coast (Reese et al. 2005; Ressler et al. 2005). *N. dificilis* is associated with the central portion of the California Current and does not appear to vertically vertically migrate to depths above the thermocline (Brinton 1962). *E. pacifica* is considered to be a warmer-water species, and is often found in highest abundances at the shelf-break. *N. dificilis* is also

Table 2. Number of taxa, relative percentage contribution of each taxa category to overall diet, and frequency of occurrence of each taxa by samples (in parentheses) in the diet by year.

TAXA	NUMBER OF ITEMS		PERCENT OCCURRENCE (*frequency of occurrence*)	
	2004	**2005**	**2004** *(n = 1595)*	**2005** *(n = 555)*
Actinopterygii				
All fish	853	154	0.541 (*0.84*)	0.277 (*0.70*)
Unidentified fish	835	150	0.529 (*0.69*)	0.256 (*0.68*)
Protomyctophum crockeri	5	1	0.003 (*0.01*)	0.004 (*0.01*)
Symbolophorus californiense	4	1	0.003 (*0.01*)	0.002 (*0.01*)
Ceratoscopelus townsendi	3	---	0.002 (*0.01*)	-----
Diaphus theta	1	2	0.001 (----)	0.004 (*0.01*)
Stenobrachius leucopsarus	---	1	-----	0.002 (*0.01*)
Unidentified Zoarcid	1	---	0.001 (----)	-----
Microstoma sp.	3	---	0.002 (*0.01*)	-----
Crustacea				
Unidentified crustacean	79	13	0.035 (*0.12*)	0.022 (*0.31*)
Euphausacea				
All euphausiid	312	444	0.284 (*0.39*)	0.562 (*0.57*)
Unidentified euphausiid	249	177	0.160 (*0.31*)	0.319 (*0.52*)
Euphausia pacifica	194	117	0.122 (*0.20*)	0.211 (*0.31*)
Thysanoessa spinifera	4	---	0.002 (*0.01*)	-----
Nematoscelis dificilis	---	18	-----	0.032 (*0.02*)
Amphipoda				
All amphipod	69	21	0.043 (*0.11*)	0.038 (*0.09*)
Unidentified amphipod	10	---	0.006 (*0.02*)	-----
Hyperia medusarum	17	11	0.011 (*0.03*)	0.020 (*0.04*)
Paracallisoma coecus	41	10	0.027 (*0.07*)	0.018 (*0.05*)
Cephalopoda				
Unidentified cephalopod	50	14	0.030 (*0.11*)	0.025 (*0.11*)
Hydrozoa				
Velella velella	41	18	0.026 (*0.06*)	0.032 (*0.06*)
Isopoda				
Cirolanidae	22	5	0.014 (*0.05*)	0.009 (*0.03*)
Cirripedia				
Lepas sp. cyprid	13	15	0.008 (*0.02*)	0.027(*0.03*)
Decapoda				
Unidentified decapod	9	9	0.006 (*0.01*)	0.016 (*0.05*)
Calanoida				
Unidentified copepod	9	1	0.005 (*0.02*)	0.002 (*0.01*)
Insecta				
Unidentified insect	9	0	0.006 (*0.01*)	-----

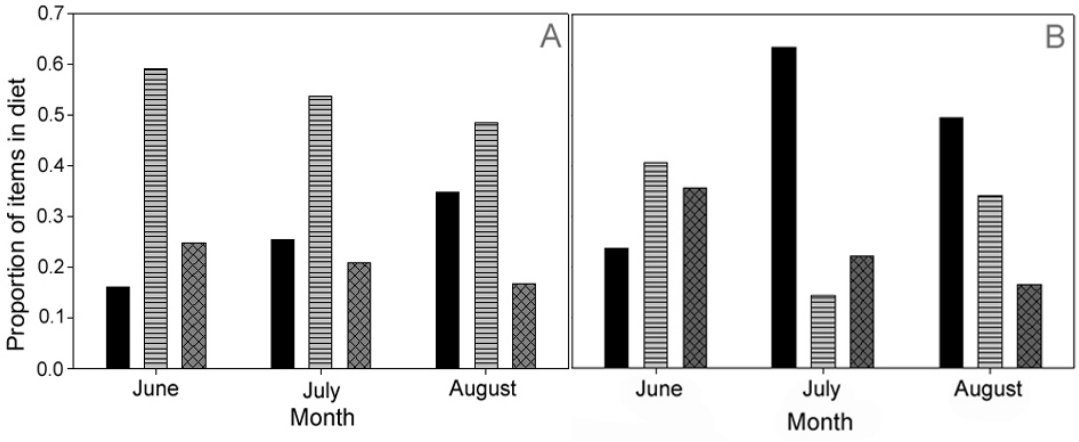
associated with warmer waters, while *T. spinifera* is identified as a cooler-water, mid-shelf species (Brinton 1962; Peterson et al. 2000; Reese et al. 2005).

Other diet items of note included the deep water amphipod *Paracallisoma coecus*, which was found to be the second-most important diet item for Leach's storm-petrels in British Columbia (Vermeer & DeVito 1988), but composed only two percent of the diet at Saddle Rock. *P.coecus* was half as abundant in 2005 as it was in 2004, but occurred more frequently in samples in 2005. The hyperiid amphipod *Hyperia medusarum*, common in temperate and polar waters worldwide and known to be a parasite on large medusae (Vinogradov 1986; Towanda & Thuesen 2006), was twice as abundant in the diet in 2005 as in 2004. Additional items representative of the diel vertically migrating community include cephalopods, unidentified decapods and calanoid copepods. Cephalopods may be present in the neuston due to vertical migration, or may be floating on the surface as a result of post-spawning mortality (Boyle & Rodhouse 2005). *Lepas* sp. cyprids were twice as abundant in the diet in 2005 as in 2004. The hydrozoan *Velella velella* was the only member of the obligate neuston eaten by the storm-petrels. A new species of isopod which has possibly been seen before only in the diet of Fork-tailed and Leach's storm-petrels in British Columbia (Vermeer & DeVito 1988) was also discovered, and is in the process of being described.

When grouped by month, opposing trends in relative abundance of fish and euphausiids can be seen (Figure 5). In 2004, relative abundance of euphausiid increased across months while relative abundance of fish decreased across months. In 2005, sample sizes in June and July were too small to allow for comparison (Figure 3),

but August of that year shows higher relative abundance of euphausiid than fish, opposite to that observed in August 2004.

Figure 5: Relative proportion of fish (dark solid), euphausiid (light grey) and all other (dark grey) diet items in the summer months of: (a) 2004 and (b) 2005.



Occurrence of non-prey items in samples

Occurrence of plastic in seabird diet has been well-documented (Baltz & Morejohn 1976; Furness 1985; Azzarello & vanVleet 1987). At this colony of storm-petrels, plastic occurred in 7% of all samples (7% in 2004, 5% in 2005). Most items were small, hard and light blue or white colored. One short length of fishing line and one thin sheet of plastic were also found. Number of plastic particles per sample ranged from zero to five. Contribution of plastic to the diet by date ranged from 0 to 11%.

Of the 46 nematodes collected throughout the project, none were identifiable beyond genus level. Those identifiable to genus were *Anisakis* sp. All but one nematode were members of the Family Anisakidae. Of the 609 samples with identifiable items, 32 contained nematodes (5% frequency of occurrence). Frequency of occurrence was 6% in 2004 and 5% in 2005. Number of nematodes per sample ranged from 0 to 2.

Cardiodectes medusaeus, a parasitic copepod associated with species of myctophid fish, was also documented in the diet samples. This copepod burrows into the cardiac cavity of its host, and has been found in most of the species seen in Leach's storm-petrel diet, including *Diaphus theta, Ceratoscopelus townsendi, Stenobrachius leucopsaurus* and *Symbolophorus californiensis* (Boxshall 2000). Incidence of parasitism by *C. medusaeus* in these species ranges from 5 – 56% (Perkins 1983). Nine copepods were found in 2004 and one in 2005.

Community Analysis

Diversity index values were very similar across years, as was evenness (Table 3). Analysis of diversity by month reveals that the highest diversity in diet is in July (H' = 2.01), followed by August (H' = 1.81), with the lowest diversity seen in June (H' = 1.71). Evenness also increased over the summer.

Table 3. Results of netting effort and indexes of community variation by date and year

Year	Number of sampling dates	Number of samples with identifiable items	Total net time (hours:mins)	Diversity (H')	Evenness (J')
2004	17	433	81:02	1.88	0.70
2005	5	176	25:12	1.82	0.71

Analysis of *a priori* conditions showed a significant difference in overall diet composition between dates, with the global test revealing a dissimilarity between dates of R = 0.047 with a significance level of 0.2% (equivalent to p = 0.002). Differences between months were tested and showed no significant differences between June and July (R = -0.040, 58.9% significance) or between July and August (R = 0.019, 50.2%

significance). The difference in diet composition between June and August was significant (R = 0.306, 1.9% significance).

Date associations.

Cluster analysis results further demonstrated that, while there was an overall tendency for clustering of dates to separate by early- to mid-season dates and mid- to late-season dates, this pattern was not universal (Figure 6). At the 76% similarity level the data

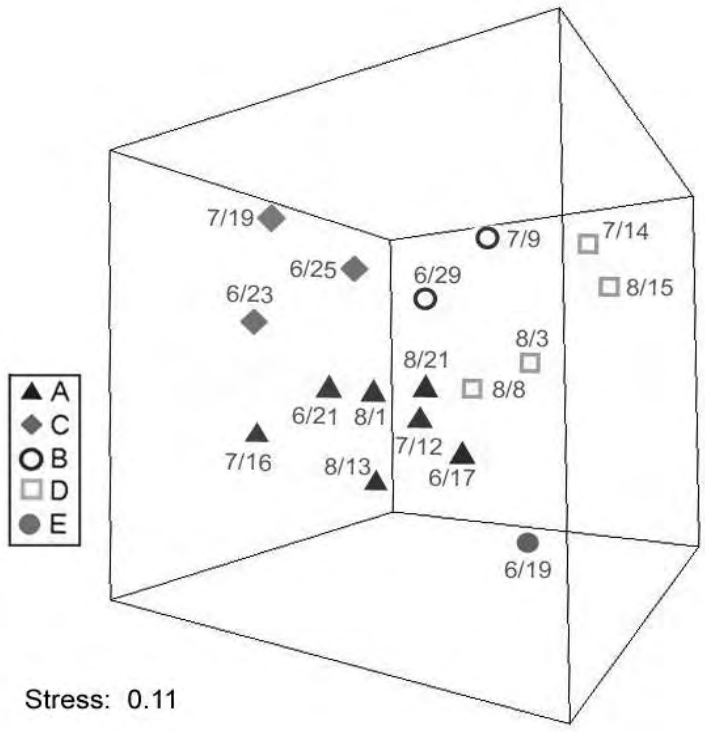
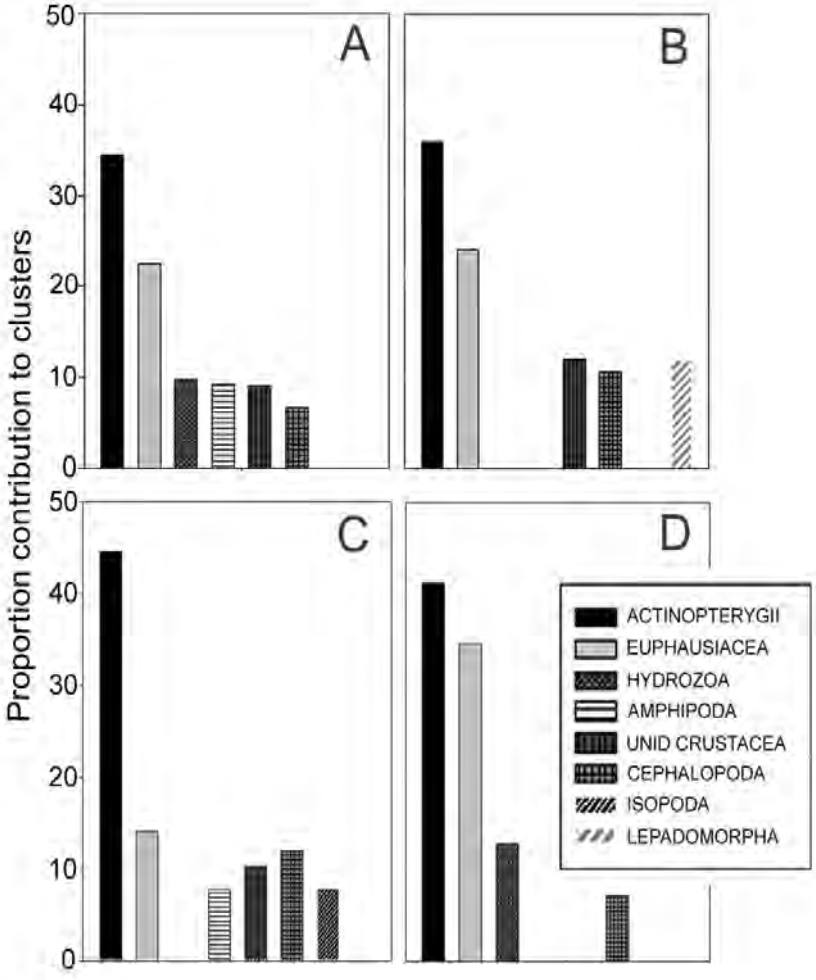


Figure 6: Three-dimensional non-metric multi-dimensional scaling plot of date association clusters.

exhibited four distinct clusters and one non-clustered date. Fish contributed most to the similarity within groups (Figure 7). Presence of hydrozoans and cephalopods contributed to similarity of groups A and D, with unidentified crustaceans and amphipods also affecting similarity in group A. Unidentified crustaceans and cephalopods influenced similarity in groups B and C. A high relative contribution of

fish, low contribution of euphausiids, and amphipods and lepadomorphs also contributed to similarity in group C.

Figure 7: Proportion each taxa contributes to similarity within clusters.

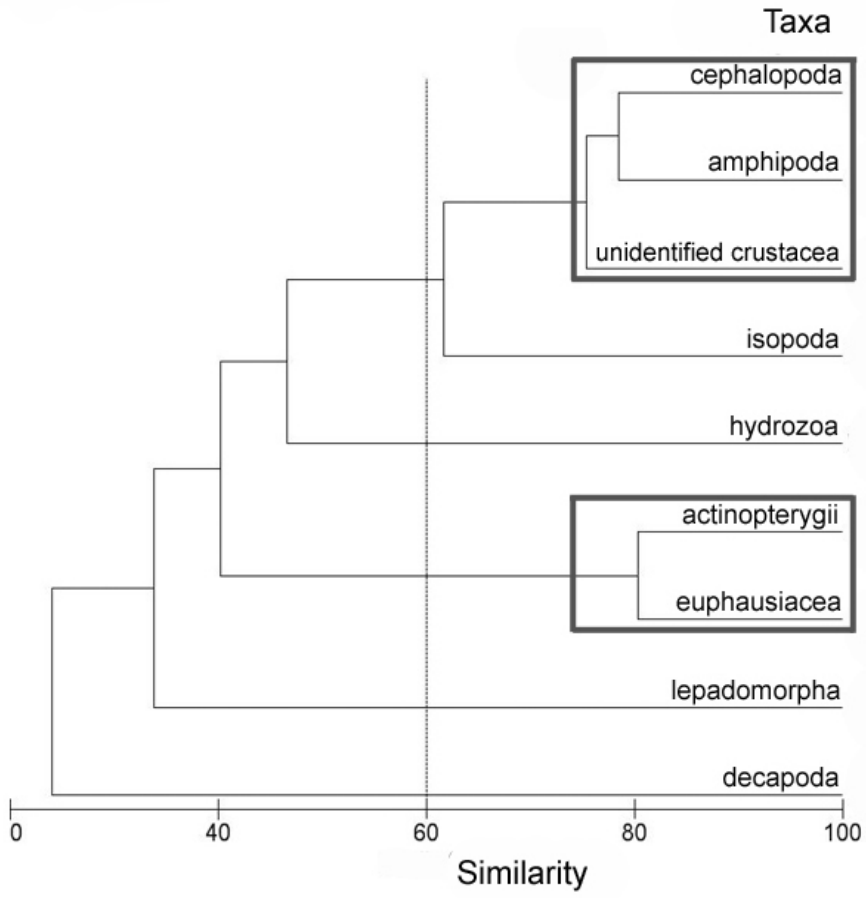


Level of stress, a measure of the adequacy of the distributional fit into dimensional space defined by Bray-Curtis similarities, was significantly higher in 2-dimensional configuration (0.19) than in 3-dimensional space (0.11) for date data (Figure 6). With lower stress levels, details become more reliable, therefore all NMDS plots are shown in 3-dimensional configuration.

Taxa associations.

Stress of the taxa association NMDS configuration in 2-dimensional space was higher (0.05) than in 3-dimensional space (0.01). NMDS plots of taxa associations reveals that, at the 60% similarity level, the euphausiid and fish groups cluster together (Figure 8).

Figure 8: Dendrogram of taxa associations with similar clusters delimited at the 60% similarity level.



This pattern is not unexpected as euphausiids are an important prey species of myctophid fish, including *Stenobrachius leucopsaurus* and *Diaphus theta* (Tyler & Pearcy 1975; Moku et al. 2000). Clustering of these two groups may also be due to the

overall prominence and frequent occurrence of these two groups in the diet. At this level, the unidentified isopod clusters together with amphipods and cephalopods, which may be an indication of an ecological association with these organisms. Lepadomorphs, hydrozoans and unidentified decapods form individual clusters distant from the other clusters, most likely due to the more limited occurrence of these items in the diet.

DISCUSSION

Reversal of percents of fish and euphausiids in the diet between years may have been due to interannual variability in ocean conditions between the two years. Onset of the spring transition, defined as the date when the net Ekman transport of the California Current switches from mostly downwelling events to the more typical spring-summer pattern of alternating periods of upwelling and downwelling, was significantly later in 2005 than in 2004. In 2004, spring transition was 20 days later than average, on 14 April (University of Washington Climate Impacts Group: (*http://www.cses.washington.edu/cig/*). In 2005, the spring transition was anomalously late, occurring off central Oregon around 24 May, with cold, dense water typical of upwelling not reaching the surface until mid-July due to a persistent stratification of water layers (Kosro et al. 2006). Timing of onset of upwelling and presence of cold, nutrient-rich waters in the surface layers of the waters off Oregon has potential to affect the prey base of Leach's storm-petrels (Brodeur & Pearcy 1992).

The relative lack of fish in the diet in 2005 as compared to 2004 may be explained by changes in ichthyofaunal distribution in 2004 and 2005. Brodeur et al., (2006) observed a northward displacement of icthyofaunal species in 2005 in excess of the effects seen in El Niño years and a 2004 ichthyfaunal distribution characterized by more northern fish

species with an influx of several southern species (e.g. *Doscidocus gigas*). Two species of myctophid fish, *Stenobrachius leucopaurus* and *Diaphus theta*, are found in high densities in the area off southern Oregon and northern California, which is assumed to be the spawning grounds of these fishes (Doyle 1992). A shift in the spawning range of these species to the area north of Cape Blanco was noted during warm conditions of the 1983 El Niño (Doyle 1992). Warm conditions in 2005 appear to have elicited the same response, as a more northerly and onshore distribution of *D. theta* was seen in 2005 (Brodeur et al. 2006). Also, in 2004, euphausiids were found to be more important in the second half of the storm-petrel breeding season diet. A low number of samples in the early part of 2005 may contribute to the apparent importance of euphausiids in that year.

Euphausiid species composition of the diet was homogenous over time, with *Euphausia pacifica* composing such a large percentage of identified euphausiid species, that use of euphausiids as an indicator of water mass movement within the foraging range went mostly untested.

Foraging theory states that organisms foraging at a distance should prefer larger, more high-energy prey items v. smaller, lower-energy items in order to maximize foraging efficiency (Montevecchi 1993). Several species of seabirds exhibit this pattern of return with larger, more energy-rich items in years of high productivity, while in years of poorer productivity, returning with more small, low-energy items and also tending to take more foraging trips (Montevecchi 1993). Foraging trip duration and number was not measured in this study, but the birds did return with a greater percentage of smaller, more low-energy items in the year of lower ocean productivity.

A comparison of the average energetic values of these two items seems to bear out this conclusion. *Euphausia pacifica*, the most numerous of the identified euphausiid species, has an average energetic value of 1138 cal/g, while myctophid fish (value from *Stenobrachius leucopsarus*, the most numerous lanternfish species off Oregon) has an energetic value of twice that amount, 2041 cal/g (bomb calorimetry values from Davis et al. 1998 and Ignell et al. 2006). These values suggest that fish, given their size and energy value per unit weight, would be the more valuable item for efficient foraging.

This study has shown that the diet of Leach's storm-petrels varies by date, in keeping with other studies that have shown storm-petrels to be generalists and opportunistic feeders (García-Godos et al. 2002).

Differences were seen in diet composition on daily, seasonal and yearly scales. Daily variation was most likely a result of the generalist foraging habits of this bird and the patchy distribution and variable availability of their prey. The significant monthly changes seen in diet composition may be due to the evolution of mesoscale oceanographic features that occur on the southern Oregon coast from June through August, but may also be due to changing diet requirements of growing chicks (Watanuki 1988). On larger time scales such as whole seasons and years, changes in the diet appear to track ocean conditions.

CHAPTER IV

CONCLUSION

In summary, the results of Chapter II showed that Leach's storm-petrels that became self-oiled on recapture in mist-nets did not show evidence of reduced survival, no matter the degree of oiling. Chapter III has shown that the diet composition of Leach's storm-petrel varies on multiple scales. A significant difference was seen in the diet on both daily and seasonal scales. On larger time scales such as whole seasons and years, changes in the diet appeared to be influenced by ocean conditions. The hypothesis that ocean conditions affect Leach's storm-petrel diet composition is investigated in the Appendix, where diet composition is compared to measurements of ocean variables.

APPENDIX

NEMATODES IN STORM-PETREL DIET

Nematodes in the family Anisakidae were also identified in the diet samples (identification courtesy of B. Baldwin). All nematodes identified to genus were of the genus *Anisakis*. Anisakid nematodes have been found to parasitize seabirds (Abollo et al 2001). Larval Anisakids, including *Anisakis* sp. are found in organisms that may be preyed on by Leach's storm-petrel including euphausiids, myctophid fish and cephalopods (Noble 1973). Noble (1973) found larval nematodes in myctophid fish species preyed on by Leach's storm-petrel, including a 15.4% incidence in *S. leucopsaurus*, and a 3.2% incidence in *D. theta*. Parasites including nematodes were also found in *C. townsendi* and *S. californiensis*. He did not find euphausiids infected by larval nematodes in the coastal waters of California, but euphausiid infection with nematodes is present elsewhere in the Pacific (Smith & Snyder 1998). The presence of *Anisakis* in Leach's storm-petrel diet contents could be an indication that this bird is a tertiary host of *Anisakis* in the marine system.

AN UNDESCRIBED SPECIES OF ISOPOD IN STORM-PETREL DIET

As noted in Chapter III, an undescribed cirolanid isopod crustacean was discovered in the diets of Leach's storm-petrel (*Oceanodroma leucorhoa*). This new isopod is a relatively common prey of storm-petrels at the Saddle Rock colony, and was first seen in

the diet of Leach's and Fork-tailed storm-petrels at Petrel Island, off Hippa Island in the Queen Charlotte Islands of British Columbia (Vermeer & DeVito 1988), where it was tentatively identified as *Cirolana californiensis* (now *Natatolana californiensis*, Keable 2006).

Fourteen of the 608 samples from both years containing identifiable prey contained *Natatolana* sp. for a total of 27 isopods, 22 in 2004 and 5 in 2005. Number of isopods per sample ranged from zero to two. In 2004 the isopod composed 2.6% of total diet, and 0.9% in 2005. The lengths of *Natatolana* sp. specimens found in Saddle Rock storm-petrel diet averaged 9 mm, minimum size was 7 mm, and maximum size was 11 mm.

The new isopod has been tentatively assigned to the genus *Natatolana* (Bruce), however, more investigation is needed to determine its exact placement within Family Cirolanidae. The ecology and relationship of this *Natatolana* sp. to other cirolanid isopods is currently being investigated, with the assistance of Dr. John Chapman at Hatfield Marine Science Center (Oregon State University).

From a search of all known species, *Natatolana* sp. most closely resembles *Natatolana californiensis* from deep sea off of southern California and *Metacirolana japonica* from the deep sea off of Japan, but differs by the: (1) non-overlap of Pleonite1 by the 7th coxa, (2) pleotelson characterized by a rounded distal region, (3) right-angle formation of the 1st anntenular article, (4) smaller number of antennule segments, (4) frontal lamina lateral margins that narrow posteriorly, (5) non-converging posterior lateral margins of the pleotelson, and other features.

Species of the cirolanid isopod genus *Natatolana* have been described in marine environments around the world, but none have been described off the temperate west coast of North America. The description of this species is in its early stages, however we have identified several characters that separate this organism from other species in the genus *Natatolana* (Keable 2006), such as including frontal lamina shape and colinear antennae. This may indicate that this isopod is member of a new genus. More investigation is needed to definitively state the taxonomic relationship of this species. Ecology of the isopod must be inferred from what is known about the diet and foraging range of its predators, and by morphology of the animal itself. From this, we can infer that this isopod is distributed beyond the continental shelf and is present nocturnally in the neuston layer. The absence of eyes in *Natatolana* sp. implies residence in deep-water habitats.

COMPARISON OF COMMUNITY COMPOSITION DATA TO ENVIRONMENTAL DATA

In addition to comparison of diet data with yearly ocean productivity based on the date of the spring transition, diet composition by date in 2004 was related to environmental variable measurements by date using a BIO-ENV procedure (Clarke & Ainsworth 1993). The BIO-ENV program determines Spearman rank correlation coefficient values for correlations between assemblage-date and environment-date resemblance matrices. For environmental variables with missing data values, visual analysis of bubble plots with environmental data overlaid on 2-dimensional NMDS plots was used instead of Spearman rank correlations to indicate possible covariation of environmental variables with diet composition.

The environmental variables here investigated for possible effects on diet composition were: sea surface temperature (SST), Bakun upwelling index (UI), presence of an upwelling jet located south of Cape Blanco, and illumination level on the foraging grounds.

Sea surface temperature was used as a possible co-variate of diet composition because, in an upwelling-dominated region such as the California Current, colder SST is generally associated with increased productivity (Laurs 1967). SST data was obtained from NOAA National Buoy Data Center (http://www.ndbc.noaa.gov/) for buoys 46027, located 8 nautical miles (nm) west off Crescent City, California (Figure 1), buoy 46002, 275 nm west of Coos Bay, Oregon and buoy 46015, 15 nm west of Port Orford, Oregon. Temperature data from each sampling date and from four time-periods were investigated for correlation with diet composition. Time-lags for the SST data from buoy 46027 were obtained using Fourier analysis (Statistica 2005) to indicate significant temperature cycles within the presumed time range that Leach's Storm-petrel begins breeding (Harris 1974) to the end of sampling (Julian dates 120 – 233). Fourier output was smoothed using a Hamming window of five, and the presence of periodicity in the data was determined by visual inspection of histograms of spectrogram values. Cycles with a periodogram value >20 were considered significant. If a spectral density diagram showed a large number of significant values, the shortest significant period was used. Data were then binned and averaged according to the calculated lags, and the four most recent lags were individually compared to diet composition. Data from buoys 46002 and 46015 were not available until 30 June in 2004, therefore relatedness of SST data

from these buoys to diet composition was determined by visual analysis a date-cluster NMDS plot overlaid with bubbles of a size corresponding to SST values.

The amount and direction of cross-shore transport (upwelling/downwelling) can also be an indicator of productivity and is often related to sea surface temperature, especially in regions over the continental shelf (Laurs 1967). Strength upwelling in southern Oregon can indicate the presence of an upwelling jet, which may carry more productive waters far into the offshore waters where Leach's storm-petrels forage. The Bakun UI approximates the amount of water transported in a cross-shore direction as measured by wind stress based on geostrophic pressure fields. UI for 125º W 42º N was obtained from NOAA Pacific Fisheries Environmental Laboratory (http://www.pfeg.noaa.gov/). A correction factor of 600 was added to the UI to eliminate negative values before applying a Fourier analysis using the same treatment as SST. Periodicity and lags were calculated with the same methods as were applied to SST. UI from each sampling date and the four most recent lags were used in correlations with assemblage data.

Presence of an upwelling jet south of Cape Blanco was ascertained from SST satellite image data from NOAA's Comprehensive Large-array Stewardship System (CLASS) and from NOAA Coastwatch composite images (Aqua/Terra MODIS satellites). Resolution of SST data was 14 km^2 from CLASS satellites and 1.4 km^2 from Aqua and Terra. The upwelling jet was assessed by visual inspection of sea-surface contours overlaid on CLASS images, and was considered to be present when a continuous negative temperature differential of at least three degrees reached 100 km offshore within the birds' estimated foraging range. For the purposes of this study, the birds' foraging range was estimated to extend in a 150 km radius from the breeding colony,

covering an area which included the continental slope, but not the continental shelf, in keeping with the birds' known distribution at sea. Only image areas with 10+ observations were used. Presence of the upwelling jet was verified using Coastwatch images where possible.

Light levels can affect the degree of vertical migration in storm-petrel prey organisms (Roe 1983), and thus may affect availability of that prey in the neuston layer. Moon phase percent was used as proxy for illumination levels on the foraging grounds, and was estimated as three categories, each corresponding to a quarterly phase of the moon (full, waning/waxing and new).

Visual analysis of overlaid graphs of environmental variables reinforced the Spearman rank correlation results showing no significance of the following environmental parameters on the diet composition of Leach's Storm-petrel: (1) buoy 46027 sea-surface temperature data ($R = 0.050$), (2) upwelling index ($R = -0.104$), (3) presence of the Cape Blanco upwelling jet as indicated by sea-surface temperature differential ($R = -0.118$), (4) maximum sea surface temperature within the foraging range ($R = 0.011$), (5) minimum sea surface temperature within the foraging range ($R = -0.003$), and (6) moon phase ($R = -0.061$). Additionally, no significant correlations were found for lagged SST and upwelling index data, or with SST data from buoys 46015 and 46002 as inspected visually.

The absence of any significant relationship with physical parameters used in this study is most likely due (in part) to lack of physical measurements from central foraging grounds and reliance on peripheral measurements and proxy variable, as well as

uncontrollable factors such as weather, chick age, distance to foraging grounds and other variables.

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